LBL-24307

DOE-SPONSORED MICROCOMPUTER TOOLS FOR BUILDINGS ENERGY ANALYSIS:

Applicability to Multifamily Retrofit Evaluation

Evan Mills
Ronald Ritschard

Lawrence Berkeley Laboratory
Applied Science Division
Energy Analysis Program
University of California
Building 90-3125
Berkeley CA 94720

(415) 486-6328

REVIEW DRAFT
November 30, 1987

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In this study, we catalog the existing simplified whole-building energy analysis tools for use with microcomputers and assess the suitability for retrofit analysis of four public-domain programs developed with support from the U.S. Department of Energy (DOE). The four programs are compared according to a set of basic requirements: ease of use, flexibility, modeling capabilities, and types of output. We conclude that none of the four DOE-sponsored programs evaluated in this study fills the specific needs of the in-field auditors, weatherization program designers/managers, or others making retrofit decisions for multifamily buildings. We suggest a more comprehensive follow-on evalution of the 27 private sector programs identified in the literature review and propose a five part assessment approach.

INTRODUCTION

In 1985, the U.S. Department of Energy (DOE) initiated a multi-year research program to improve the energy efficiency of existing buildings. The Lawrence Berkeley Laboratory (LBL) was given a lead role in the multifamily buildings sector including public and other federally-assisted housing. An important goal of this effort is to identify and assess simplified analytical tools used to evaluate energy and cost savings of residential retrofit options. In this report, we address the current availability, adequacy and affordability of computer-aided retrofit analysis methods. Since field practitioners are increasingly relying on microcomputer-based techniques (rather than on main-frame computer programs) because of their ease of use, speed, and cost, we limit our discussion in this report to PC (personal computer)-based methods.

At first glance, there is no shortage of microcomputer programs for buildings retrofit analysis. We identified 27 such programs, several of which reportedly are suitable for multifamily buildings. Although several state and local weatherization programs funded by the federal government, such as low-income weatherization and low-income home energy assistance program (LIHEAP) or through funds from the petroleum violation escrow account (PVEA), stand to benefit from the availability of these microcomputer programs, to date there has been no comprehensive and systematic evaluation of the software packages now in use.

In this survey, we catalog the existing simplified whole-building energy analysis tools for use with microcomputers and assess the suitability for retrofit analysis of four public-domain programs developed with DOE support. We identify the retrofit capabilities for each but do *not* test or validate the accuracy with which each program can estimate the savings for a given retrofit. Program validation, although an extremely important topic, is beyond the scope of this study.

We first review existing literature and catalog 27 PC-based programs now on the market that are applicable to building energy retrofit analysis. Our literature review also covers previous attempts at evaluating microcomputer programs. These efforts include analyses by the Building Energy Design Tool Council, evaluations for the Commercial and Apartment Conservation Service (CACS) Program, and a recent assessment for the Oregon Department of Energy.

Second, we provide narrative descriptions of four DOE-sponsored programs: ASEAM 2, CIRA, COSTSAFR, and PEAR 2. These programs are described according to building types addressed, general user features and run time, heating systems and zoning capabilities, output reports, economic features, and other miscellaneous features.

Next, we compare the four programs according to a set of features that are important for any simplified calculation procedure used in energy retrofit analysis. These basic requirements include ease of use, flexibility, modeling capabilities, and types of output.

We conclude that none of the DOE-sponsored tools when considered separately fill the needs or meet the budgets of field practitioners (i.e., weatherization program designers/managers or auditors) who perform retrofit analysis of multifamily buildings. However, taken together, these tools demonstrate most of the necessary features. Finally, we recommend a follow-on survey of state weatherization programs and program managers to determine their retrofit analysis capabilities and needs. After the survey is conducted, we further recommend a more comprehensive and systematic follow-on evaluation that includes other programs from the list identified in the literature review. The potential usefulness of such an evaluation to future state and local weatherization efforts may be quite significant. In a review of the progress of weatherization efforts to date, it was concluded that success in the future is related to the ability to quickly and accurately determine the optimal combination of retrofit measures for several building types in different climates.[1]

LITERATURE REVIEW

The National Directory of Energy Software for Microcomputers lists well over 100 programs for buildings energy analysis. Using this and other sources, we identified 27 programs that have whole-buildings capabilities and appear to be applicable to multifamily buildings. See Appendix A for a listing of the programs, vendors, and costs.

Three previous efforts, which have contributed to our understanding of microcomputer evaluation, are briefly described below.

Building Energy Design Tool Development Council Methodology

In July 1984, the Building Energy Design Tool Development Council prepared for DOE a systematic procedure for assessing computer programs. The result was the detailed *Design Tool Evaluation Report,* which contains checklists and text describing user features and technical capabilities as outlined in Table 1.

This report provides an elaborate set of worksheets and instructions to guide a reviewer. The results are condensed to varying levels of detail, including a one-page summary sheet, one-page key characteristic list, two-page check-list, and a lengthy narrative report. The report also includes prototype descriptions of residential and commercial buildings[2] to be used in doing test runs. The simulation results can then be compared with benchmark energy-use ranges provided for Washington D.C. weather for each

1. U.S. Government Acounting Office, 1985. "Low-Income Weatherization--Better Way of Meeting Needs in View of Limited Funds", Washington, D.C.

2. The LBL prototypical ranch house used in the "Affordable Housing Through Energy Conservation—A Guide to Designing and Constructing Energy Efficient Homes", and the commercial data set based on the prototype developed for DOE's "Small Office Building Handbook: Design for Reducing First Costs and Utility Costs". Both prototypes were developed for use in conjunction with extensive DOE-2 simulation work.

Table 1. Design tool checklist.*	
User Features	*Technical Capabilities*
Hardware and software requirements	Heat transfer methods
Identifies applications and building types	Time-steps
HVAC systems available	Building loads factors taken into consideration
Solar capabilities	Zoning capabilities
Cost of use	Solar systems taken into consideration
Input/output units (english, metric)	Control systems
Validation/inter-calibration efforts	Domestic Hot Water systems
	Economic calculations
	Output report descriptions

*Source: "Evaluation Procedure for Building Energy Performance Prediction Tools: Volume 1." The Building Energy Design Tool Development Council. July 1984.

prototype and for several HVAC configurations. The framework has so-far been applied to four programs: SERI-RES (main-frame), CIRA, ASEAM 1, and CALPAS 3 (see references).

Microcomputer Tool Evaluations for CACS

A substantial number of prior microcomputer tool evaluations were performed as part of the former Commercial and Apartment Conservation Service (CACS) Program.[3] The Program required utilities to offer free energy audits to its customers in small commercial buildings and in apartments with five or more units. The audit reports were to include recommendations for retrofit measures with less than seven-year simple payback times. Table 2 lists the measures formerly addressed in CACS audits.

Table 2. CACS Program-Mandated Apartment Retrofit Measures*	
Waste-heat recovery: A/C to DHW	Furnace flue modifications
Ceiling insulation	Daylighting retrofits
Passive solar thermosyphon air systems	Solar domestic hot water
Sunspaces	Solar pool heaters
Window shading/heat-gain retardants	Pipe and duct insulation

*Source: Federal Register/Vol 50. No 180/Tuesday, September 17, 1985, pages 37829-37830.

3. CACS was terminated about one year ago, except in Michigan where it will go on for at least three more years, although many utilities have continued to offer CACS-like services.

Much of the computer validation work was conducted during the process of granting approvals for the use of software packages in the CACS program. Yet this work did not cover the range of software packages available. Programs written by Enercom, Xenergy, Morgan Systems, and Volt were approved, with some exceptions for solar measures.[4]

In May 1986, the Minnesota Department of Public Services (Louis Goldberg) reviewed two programs—ENSIM and TRAKLOAD—both on the basis of algorithm quality and user features. ENSIM, developed by W.S. Fleming and Associates, is no longer supported and has been replaced with the improved ASEAM 2 program. TRAKLOAD—written by Morgan Systems—is still marketed and supported. To make the comparisons, DOE 2.1B (a main-frame building simulation code) was used to establish a benchmark for a three-story, six-unit multifamily building, heated with a single-pipe steam system. The building was also monitored by the City of Minneapolis for several years.

The retrofit assessments addressed the following measures:

- air conditioner replacement,
- heating control systems (night setback/setup, demand control, thermostatic radiator control valves, outdoor reset, economizer, deadband thermostat, fan timers, and modular boiler controls),
- heat-recovery systems (air-conditioner desuperheaters, heat pump water heaters, heat and reclaimer devices),
- furnace or utility plant modifications (intermittent pilot ignition devices, replacement burners, and replacement or additional furnace or boiler),
- distribution system modifications and replacement (improved flow-control devices, improved pipe or duct routing, flow-balancing mechanisms, and point-of-use water heaters),
- insulation (ceilings, attics, or roofs; heating or cooling supply or return ducts, floors, heating or domestic hot water supply pipes, walls, boilers, and hot water holding tanks),
- lighting systems (reduced lighting, operating time control, lamp replacement, and daylighting controls),
- passive solar spaceheating, solar DHW, and solar pool heaters,
- weatherstripping, and
- window and door system modifications.

4. W.S. Fleming and Associates noted that it would cost them $20,000 to perform the CACS certification runs.

An important point made in the report is that the ability of a program to model energy use—especially in the case of a retrofit measure—is quite dependent on the creativity and skill of the user, warning that the necessary manipulations may be arbitrary. In this light, the report restricted the comparison to measures explicitly incorporated within the programs.

Neither of the programs included thermostatic radiator valves (TRVs), an effective multifamily retrofit, or solar space-conditioning or DHW systems, nor were they capable of using actual utility data, although TRAKLOAD was able to adjust the simulation so that annual totals agreed with a metered baseline. The Minnesota report provides a useful discussion of validation and intercalibration issues.

Oregon Department of Energy Evaluations

The City of Portland Energy Office has also evaluated for the Oregon Department of Energy the suitability of a number of microcomputer tools for multi-family audits.[5] The investigation was prompted by the diffulties found in collecting and analyzing data and generating the desired report format with BESA.[6] The evaluation focused on (1) ease and appropriateness of use for heating system and shell retrofits on oil-heated dwellings, (2) accuracy and quality of output, and (3) level of skill required by the user. Programs included BESA (original and updated), TRAKLOAD, VCACS, ASEAM 2, Multifamily Building Audit (Center for Neighborhood Technology) CALPAS 4, CMH-2, XENCAP, SEA, and PEAR 2. An interesting approach included in the evaluation is the use of non-commercial spreadsheet programs. The "pros-and-cons" evaluation framework provides very instructive discussion of user time required for each audit and data input as well as skills and equipment needed by the user.

In order of preference, TRAKLOAD, CNT's multifamily audit program, and the spreadsheet approach were rated the highest. BESA was found to be more suitable for HVAC system design than for audit and retrofit analysis applications.

DOE-SPONSORED MICROCOMPUTER TOOLS

In the remainder of this report, we focus on the four DOE-sponsored tools: ASEAM 2, CIRA, COSTSAFR, and PEAR 2. In Appendix B, we present a side-by-side assessment of the programs' characteristics using a framework that can be easily applied to other software systems. The attributes we selected reflect a tool's ability to model buildings under existing conditions and to assess retrofit options. Appendix B consists of four tables that summarize the programs, in the categories of General, User Features, Modeling Capabilities, and Retrofit Analysis. In Appendix C, we provide sample output for

[5] "Evaluation of SHOW Multi-family Enegy Audit Methodology", David Tooze, Portland Oregon Energy Office. 1987 (SHOW = State Home Oil Weatherization.)

[6] Building Energy System Analysis retrofit program, Candaplan Resources, Inc., Ontario, Canada.

each program.

Following are narrative descriptions of each program. They generally follow a five-point framework: building types addressed, general user features, and run time; heating systems and zoning capabilities; output reports; economic features; and miscellaneous features/issues.

ASEAM Version 2—A Simplified Energy Analysis Method. Developed by W.S. Fleming and Associates, Inc. Price: $70-100.

- Draft Users Manual. Assembled by the American Consulting Engineers Council (ACEC) Research and Management Foundation for the 1987 Institute on Energy and Engineering Education.

ASEAM 2 is a menu-driven program and leads the user through a series of easy-to-read screens with prompts for each input. The manual includes copies of all screens to facilitate entry of input data. These pages can also serve as a building audit record for use in the field. The program includes limited on-line help and defaults. Because the program is intended primarily for use on commercial buildings, many of the inputs are inappropriate for the multifamily buildings (e.g., HVAC and scheduling features). To some extent, the program's thoroughness compromises user ease. Run time varies substantially by the number of zones; a five-zone building takes roughly five minutes.

ASEAM 2 can model up to 10 zones, and each can have its own central HVAC and/or baseboard heating. Heating system efficiencies are calculated as a function of temperature conditions at various points in the supply stream, loads and energy use, losses, and incoming water temperature.

The program offers 13 HVAC systems and seven plants, and an option to automatically size the HVAC systems. Especially useful in multifamily applications, a detailed boiler screen contains inputs for capacity, load-management schemes for Energy Management Control Systems (EMCS), combustion air temperature, boiler pump kW, and various pathways for heat losses within the system.

ASEAM 2 provides many output reports, including energy consumption by end-use, 3-dimensional graphs of time-of-day versus month versus load and user-friendly 2-dimensional sketches of systems (DHW, space-heating boilers, chillers, and daylighting).

The Federal Buildings Life-Cycle Cost program (FBLCC) and the National Bureau of Standards Life-Cycle Cost program (NBSLCC) are incorporated into ASEAM 2 and are enhanced with menus. The new Quick Input feature uses default values from ASHRAE 90.1P (commercial standard) plus a simple description of building shape, zones, and orientations to create a standard ASEAM input file. Quick Input also generates monthly consumption reports.

CIRA—Computerized Instrumented Residential Audit. Developed by DOE at LBL, CIRA is now marketed as an IBM-compatible PC-based program under the name EEDO by Burt Hill Kosar Rittelmann Associates in Butler, PA. The only differences between these two versions is their machine language (CPM versus PC-based). Price: $395.

- CIRA User's Manual. Lawrence Berkeley Laboratory. March 1982.

CIRA is a flexible and easy-to-use program intended for single-family residences. The maximum allowable floor area is 5000 ft^2 but it can be increased by simple modification to the source code; the inaccuracies introduced by such a modification have not been quantified. The user rarely if ever needs to consult the manual because an on-line introduction (consisting of several screens) is available. The program also has lists of options, defaults, allowable numerical ranges for answers, and help screens for *each* input. CIRA will flag any existing component that may be affected by the last user change and will automatically insert new questions as needed (e.g., the user will be queried for flue gas temperature after switching from an electric resistance to a gas furnace heating system). The extensive manual contains full engineering documentation. The energy-use calculation takes roughly 30 seconds; the retrofit optimization procedure described below takes up to seven minutes.

CIRA allows for the modeling of furnaces, boilers, heat pumps, wood stoves, and baseboard heaters. Steam, water, forced air, and gravity distribution systems can also be selected.

The output is monthly heating and cooling energy plus a number of useful parameters such as solar gains, furnace on-time, and total electricity use. A Hewlett Packard calculator is built into the program and can be used to calculate new data from the standard monthly outputs. The user can draw simple graphs of any two output variables.

CIRA's most unique feature is a retrofit optimization procedure that ranks retrofit measures according to a user-defined budget. National average costs for the measures are included but can be customized by the user. One should beware the potential for misestimations of the window retrofits when windows are lumped together on one side of a building (this is desirable because CIRA only permits 30 total wall, roof, door and window components). This occurs because the program assumes one fixed cost per window plus variable cost for materials; thus, aggregation will cause an underestimation of total retrofit cost.

COSTSAFR—Conservation Optimization STandard for SAvings in Federal Residences. Developed under the Federal Residential Standard Project by Pacific Northwest Laboratory (PNL) and Steven Winter Associates, Inc. Price: Free.

- COSTSAFR—User's Manual. In Support of Proposed Interim Energy Conservation Standards for New Federal Residential Buildings. July 1986. U.S. Department of

Energy, Office of Buildings and Community Systems, Building Systems Division, Washington, D.C. 20585.

- Technical Support Document. July 1986.
- See also Affordable Housing Through Energy Conservation, Technical Support Document by Lawrence Berkeley Laboratory and Affordable Manufactured Housing Through Energy Conservation, Technical Support Document by Steven Winter Associates, Inc.

The COSTSAFR program was developed for use with the Federal Residential Energy Conservation Standard for Federally-Procured (especially military) housing. Building types include single- and double-section manufactured (mobile) homes; ranch, split-level, two-story homes; townhouses (end and mid units); and apartments (end and mid units).

Furnaces, heat pumps, and electric resistance baseboard heaters can be modeled as well as central air-conditioning. Distribution types and efficiencies are not accounted for.

COSTSAFR does not report annual energy use or savings. The program uses heating and cooling differences (i.e., deltas) from the DOE "slide-rule" data base (developed by LBL) but the output is in the form of a set of point tables, where points are given for a range of energy conservation features. The program executes a procedure that results in a simplified point system—a tabulation of point values that are climate- and building-type specific. The user computes a total point score by summing the points for each component feature included in the proposed design. A considerable number of simple hand calculations are required to execute this step. The point score must reach a pre-determined target and the reports accompany the Request For Proposal for construction approval. The score is in turn used to compute the 25-year net present value (NPV) of energy costs for the design under consideration. Given some effort, this NPV can be used to "back-calculate" annual energy savings.

The awarding of points is based on a cost data base that can be modified by the user. The cost data are highly detailed, including construction, operation and maintenance, and replacement costs and year, and salvage value. All economic calculations are based on a fixed 25-year time horizon. (The data base includes contractor costs, net of profit—profit is handled in a standard way with a multiplier.)

Because COSTSAFR is intended for new construction, a degree of "creativity" is required when applying the program to retrofit analysis. Many measures automatically accounted for in the program are not appropriate for retrofit applications, e.g., continuous vapor barriers.

Duct losses are not included in the furnace efficiency values. To account for appliances, the program uses Federal Energy Guide Labels for appliance (refrigerator/freezer and DHW) costs. The next version, which will work without a co-processor, will include low-emissivity glass, revised heat pump calculations, thermal mass, and easier-to-use point forms.

PEAR Version 2.1—Program for Energy Analysis of Residences. Developed by Lawrence Berkeley Laboratory. Price: Free.

- PEAR 2.1 User's Manual. March 1987. Energy Analysis Program. Applied Science Division. Lawrence Berkeley Laboratory, University of California. Berkeley, CA 94720.
- Y.J. Huang, R. Ritschard, J.C. Bull, S. Byrne, I. Turiel, D. Wilson, C. Hsui, and D Foley. 1987. "Methodology and Assumptions for Evaluating Heating and Cooling Energy Requirements in New Single-Family Residential Buildings (Technical Support Document)", Lawrence Berkeley Laboratory Report No. 19128.

PEAR 2 is a highly simplified, yet flexible program for new single-family homes and townhouses that uses a data base of over 15,000 DOE-2 computer simulations compiled for the DOE-sponsored "Energy Guidelines for New Single-family Residences". The user interface is organized into four input screens: building envelope, solar and HVAC equipment, appliances, and economics. The program provides a graphic presentation in the form of bar charts that distinguish among the building components' contribution to the total annual heating and cooling loads. The program calculates heating and cooling impacts instantly, displays them at the bottom of the input screens, and compares them to the previous configuration. This facilitates quick parametric investigations.

PEAR 2 can be used to analyze five building types (one-story, two-story, split-level, mid unit and end unit townhouses), three foundation types (slab-on-grade, ventilated crawl space, and basement), in 800 representative U.S. locations. Heating system choices include oil and gas furnaces, electric resistance heating, and heat pumps. No distribution system features are available.

The economics screen compares any number of saved runs (i.e., combinatons of conservation measures) to the initial base-case condition. The user must enter capital costs, fuel costs, lifetime of measure, fuel escalation rate, tax credits, and discount rate. PEAR 2 accounts for impacts of debt financing via interest rate and loan term. For each conservation measure or combination of measures, the program calculates simple payback time and the savings-to-investment ratio (SIR). A fifth screen lists economic results for up to five cases at one time. At this stage, the cost, lifetime, and tax credits can be varied to recalculate the economic indicators.

The program also includes regular, reflective, heat-absorbing glass options; subgrade insulation (down to 8 feet); most major appliances (from Federal Ratings), solar DHW, and flow restrictors.

PROGRAM EVALUATION

In this section, we first briefly describe the evaluation criteria and then compare each of the four DOE-sponsored programs against these basic elements. We believe that the best program will fully cover each element. We also discuss the implications of each program for multifamily retrofit applications. The four programs span the gambit from the fast and highly simplified PEAR 2 program, which provides annual results, to the more elaborate hourly ASEAM 2 program. Only CIRA deals explicitly with retrofit analysis. It should be noted at the outset that none of the programs considered was specifically designed for use as a multifamily retrofit analysis tool.

The programs are compared according to various elements within four major categories: ease of use, flexibility, modeling capability, and type of output. Next, we provide a brief definition and description of these features.

Because field practitioners are often unfamiliar with the more complex models like DOE-2 or BLAST and perhaps even intimidated by them, we consider *ease of use* as a very important element. This includes both how fast the program runs and what assistance is provided. We compared programs according to whether they had menus, on-line help, adequate documentation, default values, and ample technical support.

A second key element is the degree of user control over building chacteristics and economic variables, i.e, *program flexibility.* On one hand, the wider the capabilities of a given program, the more versatile it is. A detailed model can be used not only to estimate the savings for many retrofits but also to troubleshoot an existing building by varying parameters to identify the causes of high use. On the other hand, a model can be so complex and thorough (and therefore "flexible" under our definition) that the user is intimidated or paralyzed by limited knowledge about building science. Under this category, we included the following: floor area limits, use of pre-determined building prototypes, ability to change internal load assumptions, and number of geographic locations covered.

The third major category considered is the *capabilities of the model*, i.e., what can or can not be modeled. The modeling capabilities should reflect the ability to accurately evaluate the effects of a wide range of retrofit measures in multifamily buildings. Therefore, the specific criteria include modeling time-step (i.e., hourly, monthly, or annual), number of zones, system types (HVAC, distribution, and solar), and appliances. A specific technical issue related to this category concerns building zoning. In practice, each multifamily building has as many (or more) zones as apartments. This is important insofar as the thermal characteristics (indoor temperature and heat/gain loss rates) and HVAC systems differ between apartments. In addition, unoccupied areas, office space, and common space constitute distinct zones. End versus mid unit effects and uneven heating conditions create the need for modeling of individual apartments. However, a multi-zone model may not offer enough zones to achieve this (in particular, ASEAM 2 is the only truly zoned model in this evaluation and it offers only 10 zones) nor may the user have the information or patience to model a building at this level of detail. The remaining option is to model the building as one zone or to aggregate results from a number of sub-runs, each of which represents the collection of apartments with similar zoning. The literature does not offer an evaluation of the level of accuracy resulting from such an approach.

The last major category covers the *type of program output*. In this element we consider several features such as graphics, format of the results (annual, monthly and/or peak), type of economic analysis, retrofit optimization option, and compatability of output with other analytical procedures (e.g., spreadsheet programs, etc.).

In Table 3, we provide a summary comparison of the four programs according to each of the evaluation criteria. An expanded version of the comparison is also found in Appendix B in a series of tables: general, user features, modeling capabilities, and retrofit analysis. Following are additional observations on each program, based on our evaluation.

- **ASEAM 2:** This is a highly flexible program but it sacrifices user ease to an extent that may restrict its use by non-engineers. ASEAM 2 is intended primarily for commercial buildings, although in most respects it is suitable for multifamily buildings. The program offers a highly detailed boiler description. Even though the program is menu-driven and provides default and help features, the building description procedure requires a substantial amount of information. The program, however, contains many useful features including economic analysis and a wide variety of output reports. Its usability for retrofit analysis requires better treatment of appliances, and an optimization procedure. The inclusion of single-pipe steam distribution systems would also make the program more applicable to older multifamily buildings. More locations are also needed, although with some work the user can define more weather files. The run time is rather long (e.g., about 5 minutes for a 5-zone building).

- **CIRA:** This program comes the closest to the ideal retrofit analysis tool. A thorough retrofit technical/economic optimization procedure is included and most building characteristics can be easily modified via a user-friendly, menu-driven interface. A wide range of HVAC systems are available and useful graphics and tabular output are generated. Unfortunately, the program was intended primarily for single-family buildings and as a result the algorithms are often not reliable for larger, multi-zoned buildings. The run time is long in comparison to some of the other programs, but the calculation includes a cost and energy optimization for each retrofit measure.

Table 3. Comparison of Essential Program Features

	ASEAM 2	CIRA	COSTSAFR	PEAR 2.1
EASE OF USE				
Typical Run Time(IBM-XT, Hard-disk)	5-10 min	7-min	5-min	2-seconds
Menu-driven: (Yes, No)	Y	Y	Y	Y
On-Line Help: (Full, Limited, No)	L	F	L	L
Documentation: (Yes, Limited, None)	Y	Y	Y	Y
Defaults: (Yes, Limited, None)	L	Y	Y	Y
Technical Support: (Yes, Limited, None)	L	L	N	L
FLEXIBILITY				
Floor Area Limits	none	5000 ft^3	none	4000 ft^3
Pre-Determined Prototypes: (Yes, No)	N	N	Y	Y
Internal Load Variation: (Yes, No)	Y	Y	N	N
No. of Weather Stations/Locations	60+	200+	~875	~875
MODELING CAPABILITIES				
Time-step	Hourly	Monthly	Annual	Annual
No. of Zones/No. of Systems	10/10	1/1	1/1	1/1
HVAC Systems: (**Heat Pump, Furnace, Wood Electric Resistence, Boiler, Unitary Heater**) (**Central AC, Room AC,** Evaporative Cooler, Chillers, Heat Pump)	HP,ER,F UH,B CAC HP	F,B,W HP,ER CAC RAC EC	F,HP,ER CAC	F,HP,ER CAC HP
Distribution Systems: (**Single-Pipe, Double Duct, Steam, Hot Water, Forced Air, Gravity**)	DD S,HW	G,FA S,HW	none	none
Appliances: (**DHW, Refrigerator, Dishwasher,** Clotheswasher, Clothesdryer, Showerhead, **Range**)	N*	DHW,R,Cd,R	DHW,R	DHW,R,D,C,S
Solar Systems: (Sunspace, **Trombe Wall, Rockbin, Direct Gain, Domestic Hot Water, Phase Change,** None)	N	S,T, D, DHW	S,D	S, DHW
Dynamic:† (Yes, No)	Y	Y	N	N
TYPE OF OUTPUT				
Graphics: (Yes, No)	Y	Y	N	Y
Annual Energy, Monthly Energy, Peak Loads	A,M,P	A,M	A	A
Retrofit Optimization (Yes, No)	N	Y	N	N
Economics: Cost of Conserved Energy, Internal Rate of Return, Life Cycle Costs, Simple Payback Time, Savings-to-Investment Ratio	LCC	Annualized maintenance SIR, DPBT, CCE, IRR, LCC	LCC	SPT SIR
Compatibility with Spreadsheet Programs: (Yes, No)	Y	N	N	N

* ASEAM 2 can model appliances by using miscellaneous uses screen.

† Dynamic means program **recalculates** energy use when the building description is altered.

- **COSTSAFR:** The point system upon which this program was based is not intended for retrofit or actual energy analysis but rather for procurement purposes. Although the program offers an apartment building option, few of the relevant characteristics (boiler operation features, distribution systems, heating control systems, zoning, etc.) can be changed by the user. The current absence of technical support also restricts the attractiveness of the program. The run time is also rather long. The internal gains assumptions in this program are probably unrepresentative of multifamily buildings.

- **PEAR 2:** This program offers the best user-friendly "front end" of the four programs. Since the program is based on a large data base of DOE-2 results, PEAR 2 offers results from a state-of-the-art hourly simulation code that accounts for dynamic effects (such as part-load efficiencies). Yet, the user can quickly complete input screens and is required to provide a minimal amount of building information. Energy results are provided instantly. Since PEAR 2 was intended for new single-family construction, it does not include several important HVAC and distribution systems characteristic of multifamily buildings. It also does not provide an optimization capability. The internal gains assumed in this program are specific to single-family buildings.

Several features are weak or missing from all of the evaluated programs. None of the programs have been extensively validated with measured data (i.e., actual utility bills) for multifamily buildings. This leaves the user with a certain degree of uncertainty about the reliability of the program results. In addition, the programs do not consider features, such as cogeneration, demand-reduction retrofits, utility rate schedules, or data management (i.e., energy accounting and linkages to spreadsheet programs or statistical packages). Graphic and retrofit libraries could also be substantially enhanced in all cases.

CONCLUSIONS AND RECOMMENDATIONS

None of the four DOE-sponsored programs evaluated in this study fills the specific needs of in-field auditors, weatherization program designers/managers, or others making retrofit decisions for multifamily buildings. This is not surprising since these programs were originally designed for different applications (i.e., single-family or commercial buildings and new rather than existing construction). Individually, each program is strong in one or more important feature. For example, PEAR 2 is the easiest to use and the fastest program; CIRA and ASEAM 2 offer the most flexible features; CIRA seems to provide the most modeling capabilities (although not for multi-zoned buildings); and CIRA has several important types of output including retrofit optimation.

In addition to the issue of gaps in the capabilities of these four programs to adequately fill the needs of a multifamily retrofit analysis tool, we also identify the question of a program's accuracy. None of the DOE programs has received the necessary validation tests for multifamily buildings. However, both CIRA and PEAR 2 were intercalibrated with the DOE-2 simulation code. The distinction between validation and intercalibration of building energy use models is an important one. Validiation refers to a test of the program against actual data (i.e., utility bills). Intercalibration, on the other hand, refers to a program-to-program comparison, which is "blind" to actual energy performance. Discrepancies in the results from the later approach are particularly important since the effects of unanticipated occupancy, design, and/or weather conditions are eliminated as sources of disagreement. We encourage well-designed validation and intercalibration tests in any future efforts.

Since this study was a modest one, whose goals were to identify simplified tools useful for multifamily retrofit analysis and to assess public-domain programs sponsored by DOE, we suggest that a more comprehensive follow-on evaluation be conducted of the private-sector programs identified in our review. We have already collected demonstration copies or complete versions of several simplified programs specifically designed for multifamily buildings. They include BESA, CNT, and TRAKLOAD. We propose an assessment of these programs and others using the following approach:

1. Complete a similar preliminary evaluation of the 27 programs we have identified with an emphasis on a subset of those specifically designed for multifamily buildings (about 7 programs).

2. Survey state weatherization programs and meet with key state and local weatherization officials to determine their analysis capabilities and needs.

3. Field test these programs using two well-monitored multifamily buildings (e.g., the Minneapolis single-pipe building and one of the carefully-monitored buildings in Seattle) and estimate the building's energy use and hypothetical savings from a few selected retrofit measures.

4. Compare the estimates from each program with weather-corrected measured data and/or with DOE-2 simulation results.

5. Make a final recommendation for the use of one or more existing programs *or* for the development/modification of a new program to meet the need.

ANNOTATED BIBLIOGRAPHY

1. Goldberg, Louis F. "CACS Computerized Audit Program Evaluation." Minnesota Department of Public Service, Energy Division. May 1986. Comparison of the calculation methods employed in two programs—TRAKLOAD and ENSIM—and evaluation their ability to model the impacts of retrofits used in the Commercial

and Apartment Conservation Service Program (CACS) in Minnesota: Air conditioner replacement, Energy-Control Systems, Energy-Recovery Systems, Furnace or Utility Plant Modifications, Distribution System Modifications and Replacement, Insulation, and Lighting Systems. Based on a six-unit multifamily building with comparisons to measured data and DOE-2 runs. The study tentatively prefers ENSIM, although this program is no longer supported by its developers, W.S. Fleming and Associates.

2. "Evaluation Procedure for Building Energy Performance Prediction Tools: Volume 1." The Building Energy Design Tool Development Council. July 1984. Includes prototype building descriptions for commercial and single-family buildings. Provides benchmark heating, cooling, and lighting loads (kBtu/ft^2/year) for both prototypes in the Washington D.C. climate, that can be used for program intercalibration studies.

3. "Design Tool Evaluation Reports for ASEAM, CALPAS 3, CIRA, SERI-RES." The Building Design Tool Evaluation Council and ACEC Research & Management Foundation. August 1985. Applies the design tool evaluation methodology developed by the BDTDC to these four models.

4. *National Directory of Energy Software for Microcomputers.* Bureau of Governmental Research and Service. University of Oregon. October 1985. The most comprehensive compilation (over 100 programs) we have found, although is now nearly two years old. Includes one-page descriptions in standard format: Hardware requirements, program language, restrictions on use and reproduction, cost, and contact information. The Directory is divided into sections for Thermal performance/solar modeling, HVAC and lighting system analysis, energy accounting, and miscellaneous software packages.

5. "The Best Energy Software." Solar Age May 1986. Briefly describes the pros and cons of their five favorite *solar-capable* programs for whole-building energy analysis—HOTCAN 3.01, SUNPAS, SUNHOUSE, EEDO, and CALPAS 3—and two special-purpose programs—F-CHART and DAYLITE 1.0.

6. Robinson, D.A., G.D. Nelson, R.M. Nevitt, "Evaluation of the Energy and Economic Performance of Twelve Multifamily Buildings Retrofitted Under a Shared Shavings Program: Final Report." Saint Paul Energy Resource Center. St. Paul, Minnesota. July 1986. Describes the application of CIRA (aka EEDO) to the evaluation of a $450,000 shared-savings investment in 12 multifamily buildings. The retrofits included envelope and heating system measures. During the process of

applying CIRA to the multifamily buildings (to predict savings before the measures were installed) the program was calibrated to measured data. The Princeton Scorekeeping Method (PRISM) was then applied to measured post-retrofit utility data to determine actual savings.

ACKOWLEDGEMENTS

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Services Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098. The authors also wish to thank Rick Diamond, Kathy Greely, and Chuck Goldman for thoughtfully reviewing the draft report, and the several vendors who made either demonstration or complete copies of their programs available for our preliminary review.

APPENDIX A: VENDORS' LIST

List of 27 vendors.
(Application Key: Single Family, Multi-Family, Commercial)

NAME	CONTACT INFORMATION	INTENDED APPLICATION	PRICE
ADM-2	Contact: Kwok Lam Sacramento, CA (916) 363-8383)	SF,MF,C	$595
ASEAM2	Contact: Lynn Fryer Jim Fireovid 55 Colvin Avenue Albany, NY 12206 (518) 458-2249	SF,MF,C	$70-100
BESA	Contact: Yvef Lemoine Canadaplan Resources, Inc. 393 Rymal Road West Hamilton, Ontario Canada L9B 1V2 (416) 389-3893	MF,C	$950
CALPAS 4.0	Contact: Maggie Boyce Berkeley Solar Group PO Box 3289 3140 Martin Luther King Jr. Way Berkeley, CA 94703 (415) 843-7600	SF,MF,C	$795
COMPLY-24	Contact: Martin Dodd Michael Gabel Associates Oakland, CA	C	$995
CNT	Contact: John Katrakis Center For Neighborhood Technology 570 West Randolph Street Chicago IL 60606 (312) 454-0126	MF	
COSTSAFR	Contact: Alan Lee Pacific Northwest Laboratories FTS 429-7584	SF	Free
EEDO 1.0 (CIRA)	Contact: Burt Hill Kosar Rittelmann Associates 400 Morgan Center Butler, PA 16001 (412) 285-4761	SF	$395
ELECTRICHEAT	Contact: Jeff Clark Cornerstones Energy Group 54 Cumberland Street Brunswick, ME 04011 (207) 772-3900	SF,MF	$125

AUDIT (2)	Contact: Susan Booher Elite Software P.O. Drawer 1194 Bryan, TX 77806 (409) 846-2340	SF,MF,C	$295
ENERGY DESIGNER	Contact: American Institute of Architects 1735 New York Avenue, N.W. Washington, D.C. 20006 (800) 424-5080	SF,MF	
ENERGY/PC	Contact: Richard Linton Engineering Applications Specialists, Inc. 5610 Medical Circle Suite 31 Madison, WI 53719 (608) 273-0065	C	$495
EN4M	Contact: Bob McClintock MC^2 Engineering Software PO Box 430980 Miami, FL 33143 (305) 665-0100	C	$995
HOTCAN 3.01	Contact: Energy Analysis Software P.O. Box 7081 Postal Station J Ottowa, Ontario, Canada K2A 3Z6		
MICROPAS	Contact: Eric Torney Energy Toolworks 207 Kent Avenue #1 Kentfield, CA 94904 (415) 461-8077	SF	$285
PC ENERGY	Contact: P.C. Energy, Inc. 11684 Ventura Boulevard #629 Studio City, CA 91604 (818) 762-8319	SF,MF	
PEAR Version 2.0	Contact: Ronald Ritschard Lawrence Berkeley Laboratory Building 90-3125 Berkeley, CA 94720 (415) 486-6328	SF	Free
RESIDENTIAL LOADS	Contact: Cornerstones-Wright PO Box 4904 Portland ME 04112		

SEA-V	Contact: Charles Kalasinsky Firreira & Kalasinsky Associates, Inc. 4 Renwick Drive Norton, MA 02766 (617) 285-4494	C	$495
SOLAR-5	Contact: Murray Milne University of California Los Angeles Los Angeles, CA 90024 (213) 825-7370		
SUNCODE-PC (~SERI-RES)	Contact: Mark Toney ECOTOPE 2812 E. Madison Seattle, WA 98112 (206) 322-3753	SF,MF,C	$650
SUNDAY	Contact: Mark Toney ECOTOPE 2812 E. Madison Seattle, WA 98112 (206) 322-3753		
SUNHOUSE	Contact: Danny Parker Precision Environments PO Box 243 Helena, MT 59624 (406) 442-7942	SF	$104
SUNPAS/SUNOP	Contact: Solarsoft, Inc. 1406 Buringame Ave., Suite 31 Burlingame, CA 94010		
TRAKLOAD	Contact: David Krinkel Morgan Systems 1654 Solano Avenue Berkeley, CA 94707 (415) 525-4736	MF,C	$1,485
VCACS	Contact: Rick Ogel Volt Energy Sacramento, CA (916) 929-8708	MF,C	$10,000
XENCAP	Contact: Xenergy Inc. Burlington, MA	MF	

APPENDIX B: CHARACTERISTICS TABLES

Table B.1. Comparative program characteristics: GENERAL.

	ASEAM 2.0	CIRA	COSTSAFR	PEAR 2.0
INTENDED APPLICATION: (**S**ingle **F**amily, **M**ulti-family, **C**ommercial)	SF,MF,C	SF	SF,MF	SF
PUBLIC **D**OMAIN, **P**RIVATE	PD	PD	PD	PD
COMPUTER/OPERATING SYSTEM	IBM/DOS 2.0 AppleII	IBM/DOS 2.0	IBM/DOS 2.0	IBM/DOS2.0
RAM	64k	64k	256k	256k
MEMORY (kBytes)	2,145	482	500	233
REQUIRES MATH COPROCESSOR (**Y**es, **N**o)	N	N	Y	N
LIST PRICE (1987)	$70-100*	$395	Free	Free
MANUAL PRICE	included	included	included	included
DEMONSTRATION DISK AVAILABLE (**Y**es, **N**o)	Tutorial	Y	N	N
SUPPORT	limited	limited	none	limited
TRAINING	fee basis	no	no	no
WEATHER DATA TYPE	Air Force ASHRAE Bin	TMY,TRY	DOE-2	DOE-2
No. of WEATHER STATIONS	60+	200+	~875	~875
ALGORITHM/METHOD DOCUMENTATION (**Y**es, **N**o)	Y	Y		
INPUT/OUTPUT UNITS: (**E**nglish, **S**ystem **I**nternational)	E	E,SI	E	E
PUBLISHED VALIDATION STUDIES: (**Y**es, **N**o)	N	Y	N	N
CODE	Basic	Adv. Basic	C	Turbo Pascal
ENERGY-ACCOUNTING:* (**Y**es, **N**o)	N	N	N	N

Table B.2. Comparative program characteristics: USER FEATURES.

	ASEAM 2.0	CIRA	COSTSAFR	PEAR 2.0
TYPICAL RUN TIME (IBM-XT, Hard-disk)	5-minutes	7-minutes	5-minutes	2-seconds
TIMESTEP: (**H**ourly, **D**aily, **M**onthly **A**nnual)	H	M	A	A
BATCH MODE **Y**es, **N**o	Y	N	Y	N
INTERACTIVE: (**Y**es, **N**o)	Y	Y	Y	Y
MENU-DRIVEN: (**Y**es, **N**o)	Y	Y	Y	Y
ON-LINE HELP: (**F**ull, **L**imited, **N**o)	L	F	L	Y
RECALL EXISTING FILES: (**Y**es, **N**o)	Y	Y	Y	Y
DEFAULTS: (**Y**es, **L**imited, **N**o)	L	Y	Y	Y
PRE-DEFINED PROTOTYPES: (**Y**es, **N**o)	N	N	Y	Y
PREDICTED/ACTUAL ADJ:* (**Y**es, **N**o)	N	N	N	N
DATA MANAGEMENT (Spreadsheet-ready output): (**Y**es, **N**o)	Y	N	N	N
GRAPHICS: (**Y**es, **N**o)	Y	Y	N	Y

* Ability of the program to automatically adjust simulation assumptions to achieve good agreement with measured data.

Table B.3. Comparative program characteristics: MODELING CAPABILITIES.

	ASEAM 2.0	CIRA	COSTSAFR	PEAR 2.0
SOLAR: (**S**unspace, **T**rombe Wall, **R**ockbin, **D**irect Gain, **D**om. **H**ot **W**ater, **N**one, **P**hase Change)	N	S,T,D,DHW	S,D	S,DHW
No. ZONES/No. OF SYSTEMS PER ZONE	10/10	1/1	1/1	1/1
PEAK LOADS (**H**eating, **C**ooling, **N**one)	H,C	N	N	N
THERMOSTATS (**S**ummer-, **W**inter-, **s**etback)	S,W-s	S-s,W-s	W-s	W-s
COGENERATION: (**Y**es, **N**o)	N	N	N	N
INTERNAL GAINS INPUT: (**V**ariable, **F**ixed)	V	F	F	F
EXTERIOR WINDOW SHADING: (**Y**es, **N**o)	Y	Y	N	N
HEATING SYSTEMS: (**H**eat **P**ump, **F**urnace, **W**ood **E**lectric **R**esistence, **B**oiler, **U**nitary **H**eater)	HP,ER,F UH,B	F,B,W HP,ER	F,HP,ER	F,HP,ER
COOLING SYSTEMS: (**C**entral **AC**, **R**oom **AC**, **E**vaporative **C**ooler, **C**hillers, **H**eat **P**ump)	CAC HP	CAC RAC EC	CAC	CAC HP
DISTIBUTION SYSTEMS: (Single-**P**ipe, **D**ouble **D**uct, **S**team, **H**ot **W**ater, **F**orced **A**ir, **G**ravity)	DD S,HW	G,FA S,HW	none	none
PART-LOAD EFFICIENCIES	Y	Y	N	Y
ORIENTATION (number of directions)	8	continuous	1	10
APPLIANCES: (**DHW**, **R**efrigerator, **D**ishwasher, **C**lotheswasher, **C**lothes**d**ryer, **S**howerhead, **R**ange)	N	DHW,R,Cd,R	DHW,R	DHW,R,D,C,S
MAXIMUM FLOOR AREA	none	5000 ft^3	none	4000 ft^3
LIGHTING ENERGY (**Y**es, **N**o)	Y	N	N	N

Table B.4. Comparative program characteristics: RETROFIT ANALYSIS.

	ASEAM 2.0	CIRA	COSTSAFR	PEAR 2.0
ECONOMICS **C**ost of **C**onserved **E**nergy, **I**nternal **R**ate of **R**eturn, **L**ife **C**ycle **C**osts, **S**imple **P**ayback **T**ime, **S**avings-to-**I**nvestment **R**atio	LCC	Annualized maintenance SIR DPBT, CCE, IRR, LCC	LCC	SPT SIR
RATE STRUCTURES Energy: (**L**evel, **T**iered, **T**ime-**O**f-**D**ay) Demand Charges: (**Y**es, **N**o)	 L N	 L N	 L N	 L N
RETROFIT OPTIMIZATION: (**Y**es, **N**o)	N	Y	N	N
Selected Measures				
Increased Insulation: (**Y**es, **N**o)	Y	Y	Y	Y
Window Insulation: (**Y**es, **N**o)	N	Y	N	Y
Tankless Waterheater: (**Y**es, **N**o)	N	Y	N	N
Lighting Measures: (**Y**es, **N**o)	Y	N	N	N
Front-End Boilers: (**Y**es, **N**o)	Y	N	N	N
High-efficiency Furnaces/Boilers: (**Y**es, **N**o)	Y	Y	Y	Y
Radiant Barriers: (**Y**es, **N**o)	N	N	N	N
Thermostatic Radiator Valves: (**Y**es, **N**o)	Y	Y	N	N
Appliances: (**Y**es, **N**o)	N	N	Y	Y
Deadband Thermostat: (**Y**es, **N**o)	N	Y	N	N

Table B.4 (cont). Comparative program characteristics: RETROFIT ANALYSIS (cont'd).

	ASEAM 2.0	CIRA	COSTSAFR	PEAR 2.0
Selected Measures (cont'd)				
Infiltration Reduction: (**Y**es, **N**o)	Y	Y	Y	Y
Domestic Hot Water Heater Insulation: (**Y**es, **N**o)	Y	Y	N	N
Outdoor Reset Thermostat:* (**Y**es, **N**o)	Y	N	N	N
2 or 3 Glazings: (**Y**es, **N**o)	Y	Y	Y	Y
Steam-to-Water Conversions: (**Y**es, **N**o)	Y	Y	N	N
Vent Dampers: (**Y**es, **N**o)	N	N	N	N
Boiler Lockout: (**Y**es, **N**o)	N	N	N	N
EMCS: (**Y**es, **N**o)	Y	N	N	N
DHW setback: (**Y**es, **N**o)	Y	Y	N	N

* Outdoor reset effectively makes the building into one zone. Boiler firing rate is reduced indirectly because return water is routed around the boiler and back into the distribution loop/ Boiler lock-outs, on the other hand, shut down the boiler or distribution (pumping). It may be necessary to keep boiler operating to provide DHW.

APPENDIX C: SAMPLE OUTPUTS

ASEAM2

Sample output

Sample Single Run Calculation

Loads Report File: demoLA00

Report: Peak Load Summary

Space: Building
Floor Area: 5,000 sq ft Volume: 50,000 cu ft

	COOLING		HEATING
Time of Peak	Apr hour = 17		Feb hour = 5
Outside Temp	87.5 deg F		-2.5 deg F

	Sensible (BTUH)	Latent (BTUH)	Sensible (BTUH)
Glass Solar	29,365		0
Glass Conduction	8,336		-26,719
Wall Conduction	4,095		-13,125
Roof Conduction	9,750		-31,250
Opaque Solar	25,226		0
Door Conduction	0		0
Misc Conduction	0		0
Occupants	3,275	3,040	0
Lights	31,972		0
Equipment	3,840		0
Misc Sensible	0		0
Infiltration	17,666		-57,854
Total	133,526		-128,948
Total Load / Area	26.7	(BTUH/FT2)	-25.8

ASEAM2 Report: BLDG-END USE

Date: 04-07-1987

Sample Single Run Calculation

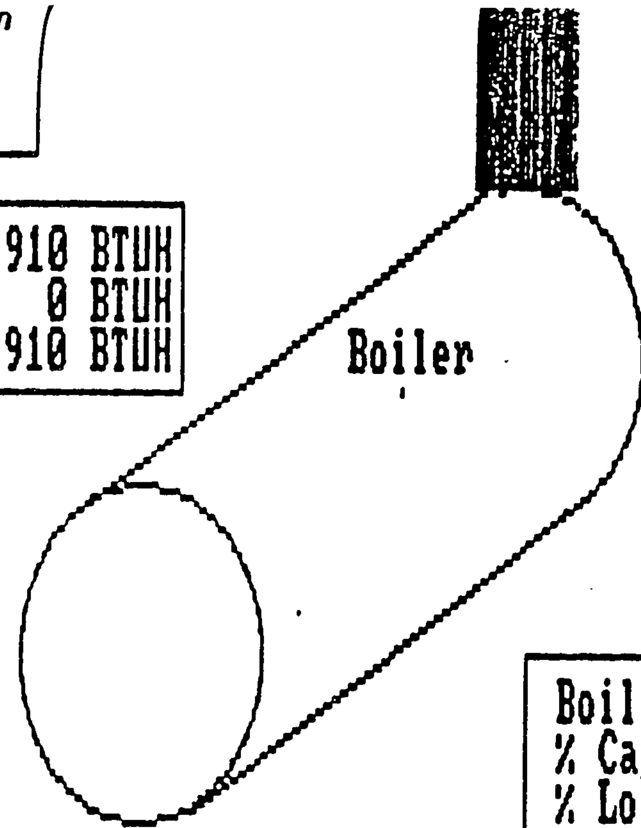
* Building Annual Energy by *
* End Use and Fuel Type *

	Nat Gas (THERMS)	Electric (KWH)	Site (MBTU)
Heating Energy			
Electric Resistance		163	0.56
Electric Boiler		87,196	297.60
Cooling Energy			
Reciprocating Chiller		18,072	61.68
Domestic Hot Water Energy			
Domestic HW Heater	420		42.05
Building Miscellaneous			
Lights		29,409	100.37
Equipment		3,259	11.12
System Miscellaneous			
Fans		12,283	41.92
Plant Miscellaneous			
Cooling Tower		1,617	5.52
Pumping		2,685	9.16
Exterior Lighting		5,000	17.06
Kitchen Range	10		1.00
Consumption Totals	430	159,685	
Unit Cost	$0.500	$0.075	
Dollar Cost	$215	$11,976	$12,192
Site Energy (MBTU)	43.0	545.0	588.1
Source Energy (MBTU)	43.0	1,852.3	1,395.4

Cycle: Occupied *Jan*
Bin Temp = 32.5 °
Bin Hours = 24.0

Heating Load	279,910 BTUH
Total Losses	0 BTUH
Boiler Load	279,910 BTUH

Bin Efficiency = 100.0 %



Boiler Plant Losses		
% Cap	0.0 %	0 BTUH
% Load	0.0 %	0 BTUH

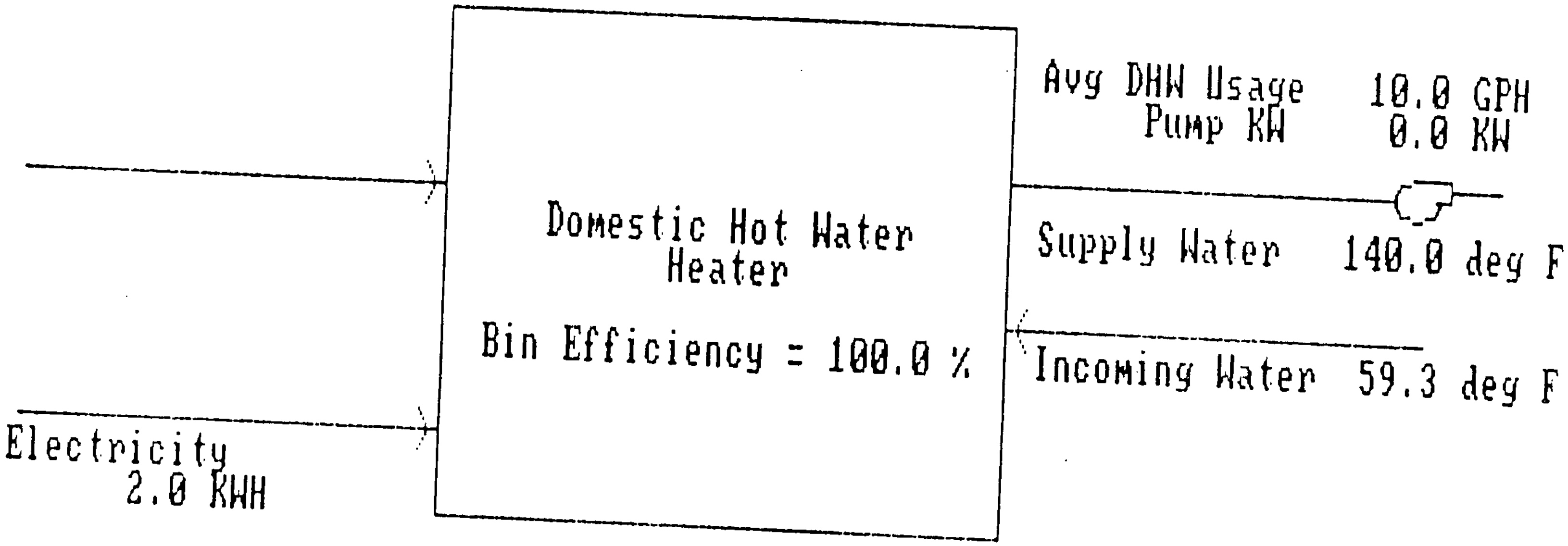
Electric
49.9 KWH

Energy (KWH)		Equivalent Full Load Hours			Annual	Seasonal
Bin	Annual	Hour	Bin	Annual	Htg Hours	Eff (%)
1,200	1,609	0.14	3.3	4	47.9	100.00

SAMPLE SCREEN OUTPUT FOR BOILER CALCULATIONS

Month = Sep   Cycle = Occupied
Bin Temp =   82.5
Bin Hours =   7.1

DHW Usage Load	6,722 BTUH
Losses Load	150 BTUH
DHW Total Load	6,872 BTUH



Energy (KWH) Bin	Energy (KWH) Annual	Equivalent Full Load Hours Hour	Equivalent Full Load Hours Bin	Equivalent Full Load Hours Annual	Annual Pump KWH	Seasonal Eff (%)
14	2,899	0.60	4.3	868	0.0	100.00

CIRA

Sample output

EEDO-------------------Energy Economics of Design Options-------------------EEDO

	a Dload	b Nload	c DayOn	d NitOn	e SpEgy	f Infil	g Telec	h DewPt	
Jan:	9.5	3.5	45.5	18.9	12.0	0.53	4889	31.0	:Jan
Feb:	6.4	2.8	38.1	16.9	9.2	0.55	3948	29.1	:Feb
Mar:	4.0	0.4	21.6	2.4	4.5	0.46	2684	38.4	:Mar
Apr:	1.3	0.0	7.0	0.0	1.3	0.41	1701	46.9	:Apr
May:	-0.3	0.0	0.0	0.0	0.0	0.36	1376	53.3	:May
Jun:	-0.9	-0.1	0.0	0.0	0.0	0.30	1332	64.3	:Jun
Jul:	-1.2	-0.3	0.0	0.0	0.0	0.28	1376	67.1	:Jul
Aug:	-1.2	-0.4	0.0	0.0	0.0	0.29	1376	69.0	:Aug
Sep:	-0.8	0.0	0.0	0.0	0.0	0.29	1332	64.4	:Sep
Oct:	1.2	0.0	6.4	0.0	1.2	0.34	1725	53.4	:Oct
Nov:	4.2	0.0	23.5	0.2	4.3	0.44	2580	43.3	:Nov
Dec:	7.4	2.3	39.8	12.2	9.7	0.52	4208	35.1	:Dec
yr(sum):	28.6	8.3	181.9	50.6	42.1	4.78	28529	595.4	:yr(sum)
yr(mean):	2.4	0.7	15.2	4.2	3.5	0.40	2377	49.6	:yr(mean)

a = A) - Dload - Daytime sensible load (MBtu)
b = B) - Nload - Nighttime sensible load (MBtu)
c = C) - DayOn - Daytime HVAC On-time (%)
d = D) - NitOn - Nighttime HVAC On-time (%)
e = E) - SpEgy - Space cond. energy use (MBtu)
f = F) - Infil - Infiltration (ac/hr)
g = G) - Telec - Overall elec use (kWh)
h = H) - DewPt - Indoor Dew Point (deg F)

EEDO-------------------Energy Economics of Design Options-------------------EEDO

```
+-A-+---+---+---+---+---+---+---+---+---+---+---+---+ 8.5       EEDO PLOT
|  a                                            |
|   a                                         A |      EEDO energy data
|    a                                       a  |
|     A                                      a  |          a      h
|     a                                     a   |        Dload  Sgain
|      a                                    a   |
|       a                                  a    |    Jan:   8.5   1.91
|       a                 H                a    |    Feb:   6.4   2.68
|        a        HhhhHhhhh hhhH          a     |    Mar:   4.0   3.54
|         A   Hhhh           hh           A     |    Apr:   1.3   4.13
|         Hhhh                 hH        a      + 3.65 May:  -0.3   4.48
|       hh a                     hhhH a         |    Jun:  -0.9   4.64
|     Hh   a                         ha         |    Jul:  -1.2   5.00
|   hh      a                        ah         |    Aug:  -1.2   4.57
| Hh        a                        a hH       |    Sep:  -0.8   3.76
|            a                      a    hhhH   |    Oct:   1.2   3.03
|             A                     A           |    Nov:   4.2   1.83
|              a                   a            |    Dec:   7.4   1.38
|               a                 a             |
|----------------aA----------------a------------0 Year(sum):  28.6  40.95
|                  aa             a             |Year(mean):   2.4   3.41
+---+---+---+---+---+aAaaaAaaaAaaaA-+---+---+---+-1.2
 Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
```

a = A) - Dload - Daytime sensible load (MBtu)
h = I) - Sgain - Solar gain (MBtu)

Meosmodold' house in DETROIT [illegible]

Spent: $3162.70 Limit: $5000.00

ORIGINAL operating cost: $1940.92/yr RETROFITTED op cost: $1253.39/yr

	Heating	Cooling	Water	Electric
ORIGINAL house (MBtu/yr)	42.07	0.00	17.58	37.75
RETROFITTED house (MBtu/yr)	15.45	0.00	9.73	37.75
CHANGE in energy	-63.3%	0.0%	-44.6%	0.0%

	Retrofit DESCRIPTION	NAME & LOCATION	change in HEATING	change in COOLING	change in WATER HEATER	change in ELECTRIC
1	Lower mtg. THERMOSTAT by 3 F always	Meosmodold GENERAL	-14.2%	0.0%	0.0%	0.0%
2	Set water htr. thermostat to 120 F	3.2 APPLIANC	0.0%	0.0%	-18.5%	-0.0%
3	Install LOW FLOW SHOWERHEAD	3.2 APPLIANC	0.0%	0.0%	-21.0%	-0.0%
4	Weatherstrip attic hatch	ROOF ROOF-CEI	-0.5%	0.0%	0.0%	0.0%
5	Install R-6 water htr. blanket	3.2 APPLIANC	0.8%	0.0%	-5.2%	-0.0%
6	Put 5.5" fiberglass batts und. floor	BASEMENT SUBFLOOR	-24.2%	0.0%	0.0%	0.0%
7	SEAL wall cracks & holes thor'ly	BASEMENT SUBFLOOR	-4.0%	0.0%	0.0%	0.0%
8	Install nighttime R-4 INSULATION	WindowS WINDOWS	-5.7%	0.0%	0.0%	0.0%
9	Install 5 inches of cellulose	ROOF ROOF-CEI	-6.6%	0.0%	0.0%	0.0%
10	Install nighttime R-4 INSULATION	Harry WINDOWS	-2.0%	0.0%	0.0%	0.0%
11	*Install 9 inches cellulose	ROOF ROOF-CEI	-1.6%	0.0%	0.0%	0.0%
12	Install NEW insulating DOOR	Garagetoins DOORS	-1.7%	0.0%	0.0%	0.0%
13	Install winter interior GLASS STORM	WindowN WINDOWS	-1.5%	0.0%	0.0%	0.0%
14	*Install nighttime R-6 INSULATION	Harry WINDOWS	-0.3%	0.0%	0.0%	0.0%

* - This replaces a previous retrofit on this component. Savings and costs are in addition to those of the replaced retrofit.

Meosmodold house in DETROITR at 619 feet

Spent: $3162.70 Limit: $50000.00

Real DISCOUNT rate (%): 3.00 Real MAINT ESC rate (%): 4.30

	Heating	Cooling	Water	Electric
Type of EQUIPMENT	Elec Baseboard	None	Electric	-na-
Fuel PRICES ($/MBtu)	19.92	19.92	19.92	19.92
Real ESCALATION rate (%)	3.00	3.00	3.00	3.00

	Retrofit DESCRIPTION	NAME & LOCATION	Initial COST	1st Year SAVINGS	Annualized MAINTENANCE	Net SAVGS to COST R
1	Lower Htg. THERMOSTAT by 3 F always ------------	Meosmodold GENERAL	$0.50	$118.99	$0.00	999.9
2	Set water htr. thermostat to 120 F ------------------	3.2 APPLIANC	$0.50	$64.65	$0.00	999.9
3	Install LOW FLOW SHOWERHEAD --------------------------	3.2 APPLIANC	$30.00	$73.54	$3.17	69.7
4	Weatherstrip attic hatch ----------------------------	ROOF ROOF-CEI	$12.00	$4.11	$0.87	7.6
5	Install R-6 water htr. blanket -----------------------	3.2 APPLIANC	$30.00	$11.32	$3.17	7.4
6	Put 5.5" fiberglass batts und. floor ------------	BASEMENT SUBFLOOR	$887.00	$202.65	$7.77	6.5
7	SEAL wall cracks & holes thor'ly ----------------	BASEMENT SUBFLOOR	$148.40	$41.06	$7.85	6.4
8	Install nighttime R-4 INSULATION ------------------	WindowS WINDOWS	$384.80	$48.16	$10.17	2.8
9	Install 5 inches of cellulose -----------------------	ROOF ROOF-CEI	$646.00	$55.53	$5.66	2.3
10	Install nighttime R-4 INSULATION --------------------	Harry WINDOWS	$272.00	$23.52	$7.19	1.6
11	*Install 8 inches cellulose -------------------------	ROOF ROOF-CEI	$231.00	$13.35	$2.02	1.3
12	Install NEW insulating DOOR ---------------------	Garagetoins DOORS	$160.00	$14.49	$6.36	1.3
13	Install winter interior GLASS STORM ---------------	WindowN WINDOWS	$327.50	$12.86	$0.87	1.1
14	*Install nighttime R-6 INSULATION --------------------	Harry WINDOWS	$33.00	$2.38	$0.87	1.1

* - This replaces a previous retrofit on this component. Savings and costs are in addition to those of the replaced retrofit.

Meosmodold house in DETROITR at 613 feet

Spent: $3162.70 Limit: $50000.00

Real DISCOUNT rate (%): 3.00 Real MAINT ESC rate (%): 4.30

	Heating	Cooling	Water	Electric
Type of EQUIPMENT	Elec Baseboard	None	Electric	-na-
Fuel PRICES ($/MBtu)	19.92	19.92	19.92	19.92
Real ESCALATION rate (%)	3.00	3.00	3.00	3.00

	Retrofit DESCRIPTION	NAME & LOCATION	Discounted PAYBACK	Cost CONSV FUEL (/MBtu)	Int RATE of RETURN	Net LIFE SAVINGS
1	Lower Htg. THERMOSTAT by 3 F always ------------	Meosmodold GENERAL	0.0yr	$0.00	999.9%	$3569.07
2	Set water htr. thermostat to 120 F -------------------	3.2 APPLIANC	0.0yr	$0.00	999.9%	$1939.06
3	Install LOW FLOW SHOWERHEAD --------------------------	3.2 APPLIANC	0.4yr	$0.38	244.4%	$2059.98
4	Weatherstrip attic hatch ----------------------------	ROOF ROOF-CEI	3.7yr	$2.13	30.3%	$79.44
5	Install R-6 water htr. blanket -----------------------	3.2 APPLIANC	3.7yr	$2.46	30.3%	$193.40
6	Put 5.5" fiberglass batts und. floor ------------	BASEMENT SUBFLOOR	4.6yr	$1.55	25.5%	$4907.63
7	SEAL wall cracks & holes thor'ly ----------------	BASEMENT SUBFLOOR	4.5yr	$2.22	25.6%	$795.90
8	Install nighttime R-4 INSULATION ------------------	WindowS WINDOWS	10.3yr	$3.66	12.0%	$687.22
9	Install 5 inches of cellulose -----------------------	ROOF ROOF-CEI	13.1yr	$4.11	9.6%	$812.49
10	Install nighttime R-4 INSULATION --------------------	Harry WINDOWS	17.6yr	$5.30	6.7%	$170.05
11	*Install 8 inches cellulose -------------------------	ROOF ROOF-CEI	21.0yr	$6.12	5.5%	$75.63
12	Install NEW insulating DOOR ---------------------	Garagetoins DOORS	22.6yr	$5.93	4.7%	$41.63
13	Install winter interior GLASS STORM ---------------	WindowN WINDOWS	27.7yr	$8.08	3.5%	$26.67
14	*Install nighttime R-6 INSULATION --------------------	Harry WINDOWS	24.5yr	$6.36	4.3%	$2.07

* - This replaces a previous retrofit on this component. Savings and costs are in addition to those of the replaced retrofit.

COSTSAFR

Sample output

SPACE CONDITIONING POINT SYSTEM FOR:
Town Houses - End units

[illegible]ITARY HOUSING PROCUREMENT
Seattle, WA

Design #: ______
Unit type: ______
Proposer: ______

[illegible] 1

[illegible] CEILING INSULATION POINTS

	Heating	Cooling
R-11	0	0
R-19	2	0
R-30	4	0
R-38	5	0
R-49	5	0
R-60	6	0

Selection for A: ______ H ______ C

[illegible]: WALL INSULATION POINTS

	H	C
R-11	0	0
R-13	1	0
R-19	4	0
R-24	6	0
R-26	7	0

Selection for B: ______ H ______ C

[illegible] FLOOR INSULATION POINTS

	H	C
Crawl Space		
R-0	0	0
R-11	16	0
R-19	19	0
R-30	20	0
Slab on Grade		
R-0	8	0
R-5_2FT	20	0
R-10_2FT	20	0
R-5_4FT	21	0
R-10_4FT	22	0
Basements		
R-0	14	0
R-5_4FT	17	0
R-5_8FT	18	0
R-10_8FT	20	0
R-0	14	0
R-11	21	0
R-19	22	0

Selection for C: ______ H ______ C

[illegible]INFILTRATION POINTS

	H	C
AVERAGE	0	0
TIGHT	9	0
VERY_TIGHT	19	0

Selection for D: ______ H ______ C

[illegible]TOTAL for page 1 (Total both columns)

SPACE CONDITIONING POINT SYSTEM FOR:
Town Houses - End units

MILITARY HOUSING PROCUREMENT
Seattle, WA
RFP# 1

Design #: ____________
Unit type: ____________
Proposer: ____________

E: WINDOW TYPE AND AREA ('10%' = 10% of heated floor area)

Window Area:	10%		12%		14%		16%		18%		20%	
Single Glass	H	C	H	C	H	C	H	C	H	C	H	C
Alum.	0	0	8	0	4	0	0	0	-2	0	-4	0
AL & TB	20	0	11	0	7	0	4	0	2	0	0	0
Wood	21	0	12	0	9	0	6	0	4	0	2	0
Double Glass												
Alum.	21	0	19	0	18	0	17	0	16	0	16	0
AL & TB	23	0	22	0	21	0	21	0	20	0	20	0
Wood	23	0	23	0	22	0	22	0	22	0	22	0
Triple Glass												
Alum.	23	0	23	0	23	0	23	0	22	0	22	0
AL & TB	25	0	25	0	25	0	25	0	25	0	25	0
Wood	25	0	26	0	27	0	27	0	27	0	27	0

Selection for E: ________ H ________ C

F. HEAT ABSORBING GLASS ('10%' = 10% of heated floor area)

Window Area:	10%		12%		14%		16%		18%		20%	
	H	C	H	C	H	C	H	C	H	C	H	C
Single Glass	-3	0	-3	0	-4	0	-5	0	-5	0	-6	0
Double Glass	-3	0	-4	0	-4	0	-5	0	-6	0	-6	0
Triple Glass	-3	0	-3	0	-4	0	-4	0	-5	0	-5	0

Selection for F: ________ H ________ C

G. REFLECTIVE GLASS ('10%' = 10% of heated floor area)

Window Area:	10%		12%		14%		16%		18%		20%	
	H	C	H	C	H	C	H	C	H	C	H	C
Single Glass	-6	0	-7	0	-9	0	-10	0	-11	0	-12	0
Double Glass	-5	0	-6	0	-8	0	-9	0	-10	0	-11	0
Triple Glass	-5	0	-6	0	-7	0	-8	0	-8	0	-9	0

Selection for G: ________ H ________ C

H. R-1 MOVEABLE INSULATION ('10%' = 10% of heated floor area)

Window Area:	10%		12%		14%		16%		18%		20%	
Single Glass	H	C	H	C	H	C	H	C	H	C	H	C
Alum.	3	0	4	0	4	0	5	0	5	0	6	0
AL & TB	3	0	3	0	4	0	4	0	5	0	5	0
Wood	3	0	3	0	4	0	4	0	5	0	5	0
Double Glass												
Alum.	1	0	1	0	2	0	2	0	2	0	2	0
AL & TB	1	0	1	0	1	0	2	0	2	0	2	0
Wood	0	0	1	0	1	0	1	0	2	0	2	0
Triple Glass												
Alum.	0	0	0	0	0	0	1	0	1	0	1	0
AL & TB	0	0	0	0	0	0	0	0	0	0	1	0
Wood	0	0	0	0	0	0	0	0	0	0	0	0

Selection for H: ________ H ________ C

SUBTOTAL for page 2 (Total both columns) .... ======== ========
Heating Cooling

SPACE CONDITIONING POINT SYSTEM FOR:
Town Houses - End units

MILITARY HOUSING PROCUREMENT
Seattle, WA
RFP# 1

Design #: ____________
Unit type: ____________
Proposer: ____________

I. R-3 MOVEABLE INSULATION ('10%' = 10% of heated floor area)

Window Area:	10%		12%		14%		16%		18%		20%	
Single Glass	H	C	H	C	H	C	H	C	H	C	H	C
Alum.	4	0	5	0	6	0	7	0	8	0	9	0
AL & TB	4	0	5	0	5	0	6	0	7	0	8	0
Wood	4	0	4	0	5	0	6	0	7	0	7	0
Double Glass												
Alum.	2	0	3	0	3	0	3	0	4	0	4	0
AL & TB	2	0	2	0	2	0	3	0	3	0	3	0
Wood	2	0	2	0	2	0	2	0	3	0	3	0
Triple Glass												
Alum.	1	0	2	0	2	0	2	0	2	0	3	0
AL & TB	1	0	1	0	1	0	2	0	2	0	2	0
Wood	0	0	1	0	1	0	1	0	2	0	2	0

Selection for I: ________ H ________ C

J. R-5 MOVEABLE INSULATION ('10%' = 10% of heated floor area)

Window Area:	10%		12%		14%		16%		18%		20%	
Single Glass	H	C	H	C	H	C	H	C	H	C	H	C
Alum.	5	0	6	0	7	0	8	0	9	0	10	0
AL & TB	4	0	5	0	6	0	7	0	8	0	8	0
Wood	4	0	5	0	6	0	6	0	7	0	8	0
Double Glass												
Alum.	3	0	3	0	4	0	4	0	5	0	5	0
AL & TB	2	0	2	0	3	0	3	0	4	0	4	0
Wood	2	0	2	0	3	0	3	0	3	0	4	0
Triple Glass												
Alum.	2	0	2	0	2	0	3	0	3	0	3	0
AL & TB	1	0	1	0	2	0	2	0	2	0	2	0
Wood	1	0	1	0	1	0	2	0	2	0	2	0

Selection for J: ________ H ________ C

K. PASSIVE SOLAR

Single Glass ('%' = window area as % of conditioned floor area)

0.57x(________ Total %) - 0.76x(________ % South) - 1.52x(________ % North) = ________ H

0.00x(________ Total %) - 0.00x(________ % South) + 0.00x(________ % North) = ________ C

Double Glass

0.06x(________ Total %) + 0.21x(________ % South) - 0.44x(________ % North) = ________ H

0.00x(________ Total %) - 0.00x(________ % South) + 0.00x(________ % North) = ________

Triple Glass

-0.04x(________ Total %) + 0.35x(________ % South) - 0.19x(________ % North) = ________ H

0.00x(________ Total %) - 0.00x(________ % South) + 0.00x(________ % North) = ________

SUBTOTAL for page 3 (Total both columns) .... ======== ========
Heating Cooling

SPACE CONDITIONING POINT SYSTEM FOR:
Town Houses - End units

MILITARY HOUSING PROCUREMENT
Seattle, WA
RFP# 1

Design #: ____________
Unit type: ____________
Proposer: ____________

L. SUNSPACES w/ Glass Roof
and Single Glass: 18.2
and Double Glass: 32.1

w/ Solid Roof
and Single Glass: 7.0
and Double Glass: 14.0

Heating:
(____________) x 0.01 x (____________) = ________ H
factor from above / sunspace length (ft)

Cooling:
No Cooling points for sunspaces

M. LIGHT ROOF COLOR
Heating:
No heating points given for roof color

Cooling:
For roof R-values below R-30 0
For roof R=values R-30 and above 0 Selection: ________ C

FINAL SUBTOTAL (Total both columns)............................======= =======
HEATING COOLING

N. HVAC EQUIPMENT
Heating Equipment Total: (Insert FINAL HEATING SUBTOTAL)
A: 65 - 0.716 x (________ SUBTOTAL) = ________ A

B: Oil furnaces and boilers: (Min AFUE = 0.50)
110 - 1.257 x (________ A) / (________ AFUE) = ________ H

Nat gas furnace and boilers: (Min AFUE = 0.50)
110 - 1.744 x (________ A) / (________ AFUE) = ________ H

LPG furnaces and boilers: (Min AFUE = 0.50)
110 - 1.644 x (________ A) / (________ AFUE) = ________ H

Elec furnaces and baseboards:
110 - 3.936 x (________ A) = ________ H

Elec heat pumps: (Min HSPF = 4.00)
110 - 18.656 x (________ A) / (________ HSPF) = ________ H

Cooling Equipment Total: (Insert FINAL COOLING SUBTOTAL)
A: -0 - 0.372 x (________ SUBTOTAL) = ________ A

B: (Min SEER = 5.00)
-0 - 13.432 x (________ A) / (________ SEER) = ________ C

SUBTOTAL for page 4 (Total both columns) ....======== ========
Heating Cooling

DOMESTIC HOT WATER AND REFRIGERATOR/FREEZER POINT SYSTEM FOR
Town Houses - End units

MILITARY HOUSING PROCUREMENT
Seattle, WA
RFP# 1

Design #: ____________
Unit type: ____________
Proposer: ____________

Insert value from Federal DHW and Refrigerator/FreezerLabels

GAS DHW HEATERS:

1 BR Units: 38 - 0.15(________) = ________
label DHW points

2 BR Units: 47 - 0.19(________) = ________
label DHW points

3 BR Units: 84 - 0.35(________) = ________
label DHW points

4 BR Units: 103 - 0.42(________) = ________
label DHW points

5 BR Units: 122 - 0.50(________) = ________
label DHW points

ELECTRIC DHW HEATERS

1 BR Units: 38 - 0.10(________) = ________
label DHW points

2 BR Units: 47 - 0.12(________) = ________
label DHW points

3 BR Units: 84 - 0.22(________) = ________
label DHW points

4 BR Units: 103 - 0.27(________) = ________
label DHW points

5 BR Units: 122 - 0.32(________) = ________
label DHW points

____
DHW points

REFRIGERATOR/FREEZERS:

21 - 0.18(________) = ________
label points

____
RFR points

TOTAL DHW HEATER AND REFRIGERATOR/FREEZER POINTS ============

COMPLIANCE FORM FOR:
Town Houses - End units

MILITARY HOUSING PROCUREMENT
Seattle, WA
RFP#

Design #: ____________
Unit type: ____________
Proposer: ____________

TOTAL POINTS:

( ) +	( ) +	( ) =	
=============	=============	=============	=================
DHW/RFR TOTAL (from p 5)	HEATING TOTAL (from p 4)	COOLING TOTAL (from p 4)	TOTAL POINTS

MINIMUM REQUIRED POINT TOTAL:

1-BR Units:	101
2-BR Units:	104
3-BR Units:	114
4-BR Units:	120
5-BR Units:	125

ESTIMATED UNIT ENERGY COST:

1 BR: (110 -_________) x (__________)/1200)+(59 - __________) = ===========

2 BR: (110 -_________) x (__________)/1200)+(68 - __________) = ===========

3 BR: (110 -_________) x (__________)/1200)+(106 - __________) = ===========

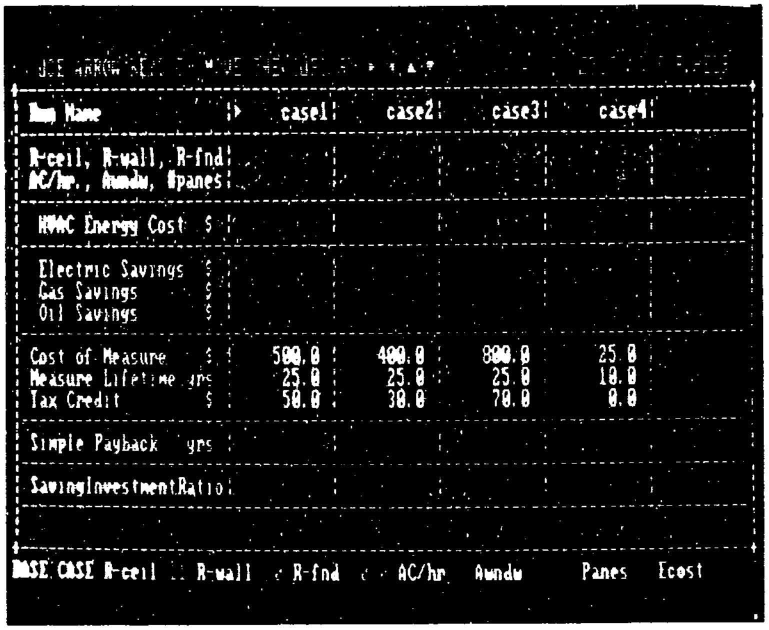
4 BR: (110 -_________) x (__________)/1200)+(124 - __________) = ===========

5 BR: (110 -_________) x (__________)/1200)+(143 - __________) = ===========

space conditioning points — conditioned floor area — DHW and appliance points

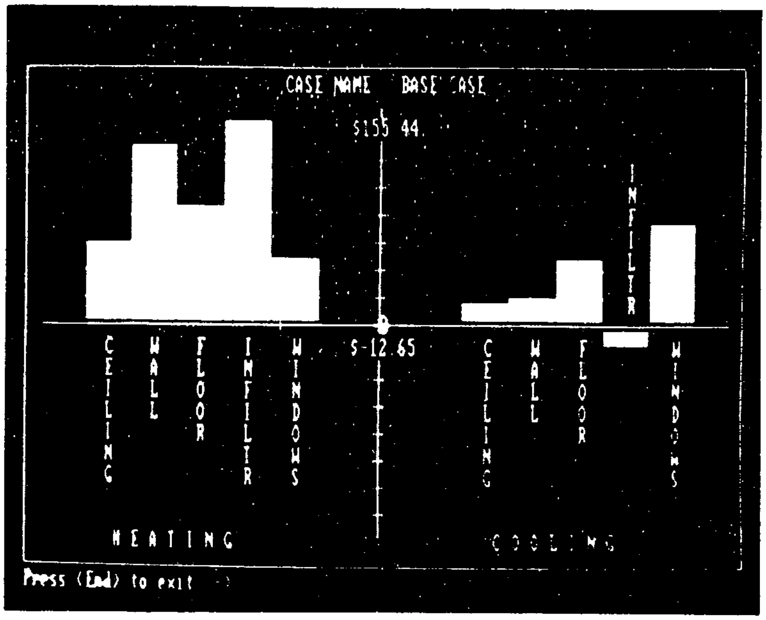
PEAR

Sample output



CBB-871-585

Economics Screen



CBB-871-589

Bar Chart